13 River Orchy

[NN 242 318]–[NN 247 331]

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13.1 Introduction

This GCR site is located in the wooded valley of the River Orchy, 10 km north-east of Dalmally. It is notable for the wealth of minor structural features that it displays, most of which can be related to the closure of an early major fold, the F2 Beinn Udlaidh Syncline. This structure folds the important sedimentary transition between the Grampian Group and the younger Appin Group (Figure 3.29). The Grampian Group is represented by psammites and semipelites, which can be shown to be overlain stratigraphically by the Beinn Udlaidh Quartzite and the Leven Schists, both of which belong to the lowest part of the Appin Group.

A major feature that makes this section invaluable for teaching and demonstration purposes is that most of the minor structures that can be examined in the field formed during the same phase of deformation, and can be related to a single large F2 fold (Figure 3.30), (Figure 3.31). The structures are particularly well seen, when water levels are low, on the well-scoured rock surfaces in the banks and bed of this spate river. The best localities are in the vicinity of the dramatic waterfall and rocky gorge at Eas Urchaidh (the ‘Falls of Orchy’, (Figure 3.29)), and along its tributary, the Allt Broileachan. This site is excellent for examining the three-dimensional form of plunging minor folds on the metre scale, and for demonstrating their relationship to the cleavages, lineations, and quartz veins found in the different rock types. Minor folds are best seen in relief in the quartzite, and in potholes in the pelite north-north-east of the Iron Bridge at [NN 243 321]; they clearly change in vergence northwards as the river section passes from the upper limb of the major fold, through the hinge-zone, to the lower limb. The curvilinear nature of the major syncline axis is revealed by the progressive change in the trend of the minor fold hinges by over 90° in less than a kilometre (Figure 3.29).

The general geology of Glen Orchy was established during the primary mapping by the Geological Survey for sheets 45 and 46 (Kynaston and Hill, 1908). However, it was Bailey and Macgregor (1912) who, recognizing the importance of the area, made the first comprehensive structural and stratigraphical interpretation. They recognized that the distribution of the three main rock types is controlled by a flat-lying, isoclinal nappe, the Beinn Udlaidh fold. These workers also found that this fold, which they considered to be as well exposed as any of the small-scale nappes in the European Alps, had been bent around a later upright fold, the Glen Orchy ‘Anticline’ (now referred to as an ‘antiform’ or ‘dome’). Cummins and Shackleton (1955, figure 7) first identified way-up structures in Glen Orchy, some tens of metres above the waterfall Eas à Chataidh at [NN 248 331], and confirmed the order of succession established by Bailey and Macgregor (1912). Thomas and Treagus (1968) studied two areas adjacent to Glen Orchy on Beinn Udlaidh in more detail and published a map of the closure of the Beinn Udlaidh Syncline. The wider area around Beinn Udlaidh, including the crucial section that constitutes the River Orchy GCR site, has recently been the subject of an extremely detailed field and petrographic study of the stratigraphy, structure, metamorphism and minor intrusions by Tanner and Thomas (2010).

The pelitic rocks at this site contain abundant millimetre-sized, partly or wholly chloritized porphyroblasts of garnet, and randomly orientated crystals of biotite, and the entire sequence has been affected by amphibolite-facies regional metamorphism.

13.2 Description

13.2.1 Stratigraphy

In the River Orchy section at [NN 242 318], rocks belonging to the Grampian Group are mainly of finely banded psammite and semipelite, with some pelitic beds a few centimetres thick that contain chloritized garnets. Thin grey quartzite beds, and thin calcareous seams are also present. The latter occur in a distinctive sedimentary association in which the dark brown-weathering calcareous bands, a few centimetres thick, are separated from the pelitic background lithology by a narrow zone of siliceous psammite. These zoned calcareous units generally have an extremely elongated pod-like geometry overall, and die out laterally within a metre or two.

The Beinn Udlaidh Quartzite is commonly coarse grained and feldspathic where it is least deformed, as in the hinge-zone of the major fold at [NN 248 332], and locally contains gritty and pebbly layers. It varies from pale grey to white or even pink in colour. Excellent examples of festoon cross-bedding (at [NN 248 331]), as well as at other localities in the quartzite on the hillside to the north-east of this GCR site, show clearly that the unit is younger than the Grampian Group. Where the boundary between the two units is least affected by later deformation, it is generally transitional over several tens of metres, with interbedding of psammite, semipelite, and quartzite ribs (Thomas and Treagus, 1968, p. 127). The northern contact is not exposed in the River Orchy section, the first exposures north of the quartzite, seen immediately above the waterfall at [NN 248 332], being of psammite with thin quartzite beds. At the south end of the section, the entire quartzite unit is thinned tectonically, and the contact can be located to within a metre or so below the dam at [NN 242 319], although Thomas and Treagus (1968) considered that the topmost 33 m of the Grampian Group at this locality constitute a ‘passage group’. A dyke and a sill-like apophyse of appinitic rock are intruded close to the stratigraphical base of the quartzite and somewhat obscure its relationship to the psammitic rocks farther downstream.

The overlying Leven Schists have a very uniform lithology and consist of finely banded, dark-grey, schistose biotite-muscovite-garnet-graphite pelites with thin layers of psammite and semipelite. The pelites are characterized by a strong bedding-parallel schistosity. They contain porphyroblasts of garnet, reaching several millimetres across in places, commonly accompanied by millimetre-sized randomly orientated flakes of biotite. Most of the garnets in the pelitic rocks have been altered to chlorite, fresh garnets being most common in the thin siliceous bands. Significantly, in the exceptionally clean exposures in the area of the gorge above the Iron Bridge, and where the river runs close to the road farther north at [NN 243 323], small-scale zoned calcareous units are found, which are identical to those seen in the Grampian Group and are also accompanied by thin beds of steel-grey quartzite.

The boundary between the Leven Schists and the underlying Beinn Udlaidh Quartzite is transitional, as is shown by the presence of thin quartzite beds within the pelite for a distance of a few metres above the main quartzite. This relationship is clearly seen at several places near to the confluence of the River Orchy and the Allt Broighleachan (Thomas and Treagus, 1968, p. 127) (Figure 3.29).

13.2.2 Structure

The Beinn Udlaidh Syncline is a sideways-closing and upward-facing syncline whose gently plunging axis changes trend from approximately east–west to north–south as it is traced southwards along the river section. This major change can be monitored by the progressive change in orientation of the hinges of the congruous minor folds ((Figure 3.29), stereoplot b). It consists of an upper limb (with inverted Grampian Group rocks lying above the Appin Group in the south of the area), and a lower limb to the north in which the Leven Schists lie above the Beinn Udlaidh Quartzite (Figure 3.29). The axial trace of the major hinge-zone passes through afforested ground to the west of the river. The marked curvature of the axial trace, as seen in (Figure 3.29), is due to the intersection of the gently dipping axial surface of the fold with the irregular topography, and is unrelated to the fold axis curvature described above.

When viewed down-plunge to between south and west, the minor folds on the upper limb are seen to have a Z-shaped vergence (Figure 3.30), which changes first to a neutral vergence in the vicinity of a poorly defined major hinge-zone at about the Iron Bridge, and then to a consistent S-shaped vergence on the lower limb. These minor folds are best seen in the quartzite and the banded Leven Schists, and have wavelengths that vary from tens of centimetres to over a metre (Figure 3.31). The axial planes of the minor folds, together with the related penetrative cleavage in the pelitic rocks, dip consistently at less than 20° ((Figure 3.29), stereoplot a). Throughout the section, a stretching lineation, seen sporadically on the bedding or foliation planes, maintains a constant trend of 190–180° and plunges at a gentle angle to either north or south. Evidence that this lineation is a stretching lineation and not a bedding-cleavage intersection lineation is seen in

the gritty and pebbly quartzite beds in the hinge-zone of the major fold around [NN 248 332], where clastic grains are clearly elongated and define a stretching lineation, which lies at right angles to the local intersection lineation and to minor fold hinges (Tanner and Thomas, 2010).

Evidence of later ductile deformation superimposed upon the major synclinal structure is restricted to the development of a crenulation cleavage, which is associated with minor folds of S-vergence in the Grampian Group rocks on the upper limb of the fold, and cross-cuts the earlier Z-folds and penetrative fabric. A weak development of a similar crenulation cleavage and lineation is also seen in the pelitic rocks on the lower limb of the Beinn Udlaidh Syncline.

The structural pattern in these rocks is beguilingly simple, and only rarely, even on the cleanest rock surfaces, are isoclinal minor folds of F1 age seen to be refolded around minor folds congruous to the major syncline (Tanner and Thomas, 2010). Care has to be taken, as some suspected refolded folds have been proved on closer examination, followed by slabbing and sectioning in the laboratory, to be of sedimentary origin In addition, examination of the garnets with a hand-lens reveals that they contain helicitic inclusion trails, which are strongly oblique to an external cleavage, which is axial planar to the F2 minor folds. Thin sections of these rocks show that (i) there is an earlier penetrative cleavage (S1), which pre-dates the formation of the S2 fabric associated with the Beinn Udlaidh Syncline, and (ii) the garnets also grew in the interval between these two deformation events (Tanner and Thomas, 2010).

13.3 Interpretation

The field relationships seen at this GCR site, supported by younging evidence from cross-bedding, show that there is a coherent stratigraphical sequence from the upper part of the Grampian Group into the lower part of the Appin Group, with no evidence of a major stratigraphical or structural discordance between the two groups (Tanner and Thomas, 2010). Of particular importance is the recognition of minor sedimentary rhythms, of unusual character, in rocks belonging to both groups. At the contact between the two groups there is evidence of sedimentary interfingering of beds, rather than tectonic interleaving. This observation is in agreement with the relationships seen at the *River Leven* and *Strath Fionan* GCR sites. This is an important conclusion as the boundary marks a major lithological change in the sedimentary record, and indeed was formerly taken to be the Moine-Dalradian boundary.

The sedimentary sequence is folded into a major syncline, the Beinn Udlaidh Syncline, which faces up to the east, and has a strongly curved axis. Previous authors have regarded this syncline and the complementary Glen Lochy Anticline as F1 structures (Cummins and Shackleton, 1955; Thomas and Treagus, 1968; Roberts and Treagus, 1975) but Tanner and Thomas (2010) have shown that it post-dates an earlier fabric (see below) and hence can be confidently assigned to the D2 regional deformation. However, only a small amount of deformation, and a gentle warping of the axial surface followed this main deformation event. This suggests that the curvature was a primary feature of the D2 deformation, and not a later effect due to refolding. Analysis of the geometrical results from this GCR site, together with those from the adjoining Beinn Udlaidh massif in which the fold is extensively dissected, indicates that this curvilinearity has resulted from the rotation of the original east–west fold axis, as seen in the least deformed rocks, towards the orientation of the north–south stretching lineation (the X-direction of the strain ellipsoid), with increasing deformation ((Figure 3.29), stereoplot b) (Tanner and Thomas, 2010). The upper limb of the fold has been most affected by this increase in strain, and the Beinn Udlaidh Quartzite found there has a platy foliation, lacks sedimentary structures, and is considerably thinner than it is on the lower, less deformed, limb. It also carries a strong stretching lineation.

A petrographical study of the garnet-bearing assemblages shows that the major F2 fold and its associated family of minor folds, cleavage, and lineations, formed *after* a deformation event which had given rise to a penetrative cleavage and was accompanied by amphibolite-facies metamorphism. Evidence of this early, S1 cleavage has been all but destroyed by later recrystallization and mineral growth in the overwhelming majority of rocks, and it is best preserved as a helicitic fabric in the garnet porphyroblasts (Tanner and Thomas, 2010). There is no evidence from this GCR site or from the adjoining area to suggest that either minor or major folding accompanied this early tectonothermal event, and its significance is still being assessed. Tanner and Thomas (2010) concluded that the rocks belonging to the Grampian Group have been affected by the same number and sequence of events as those of the Appin Group, and that there is no evidence for additional deformation phases in the older rocks. These findings support the conclusion that the

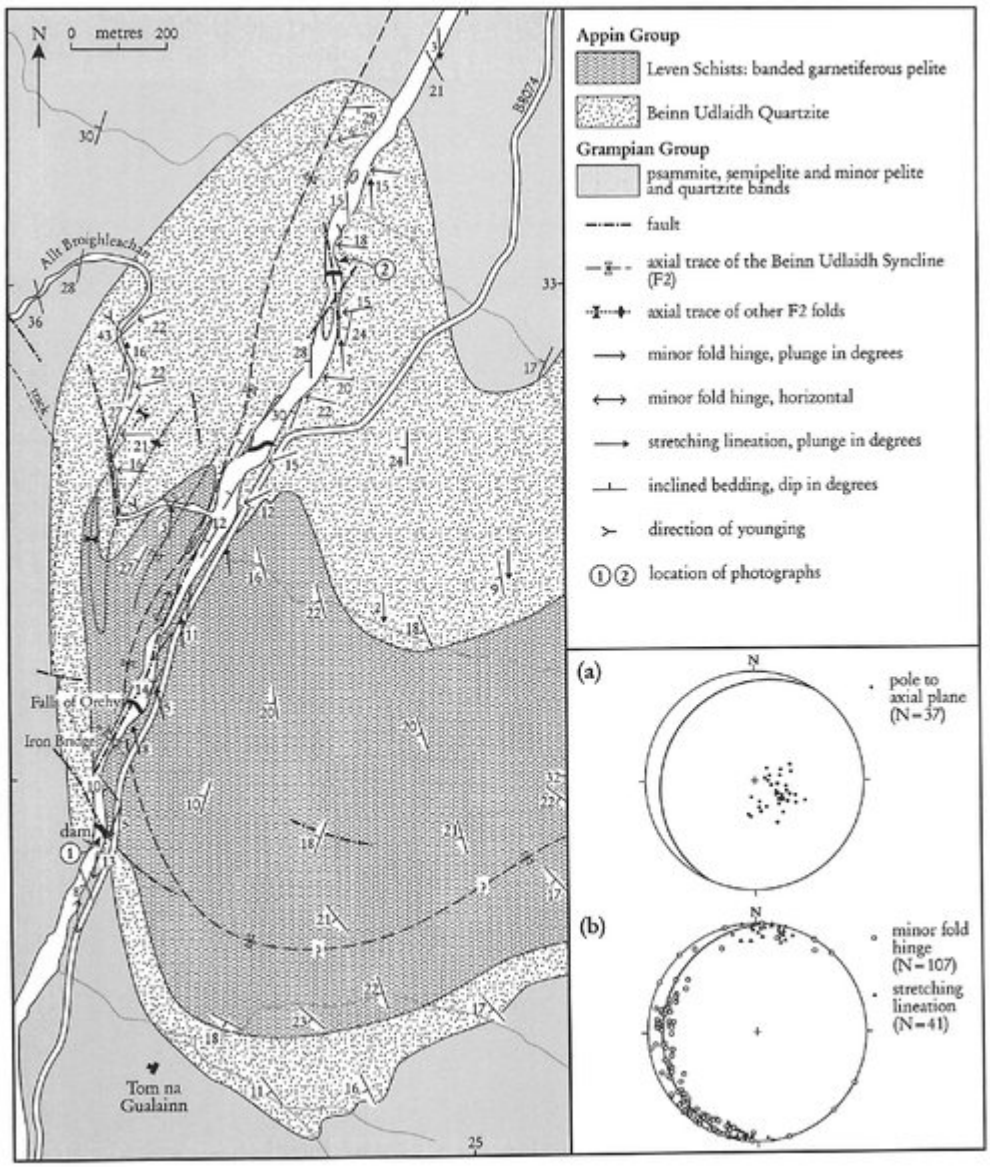
Grampian–Appin group boundary is not marked by a significant structural break.

13.4 Conclusions

The River Orchy GCR site provides an invaluable section through the upper part of the Grampian Group and its continuation upwards into the Appin Group (Lochaber Subgroup). Transitional contacts between the major rock units, coupled with sedimentary repetition of distinctive lithologies, precludes the presence of a major, orogenic, unconformity at this stratigraphical level. This finding is supported by a microscope study of rocks from this GCR site, which has confirmed the field-based conclusion that both groups have been affected by the same number of structural events, having the same intensity of development, and geometry. Thus a boundary that was formerly taken to be the contact between the Moine and Dalradian supergroups can now be confidently recognized as a normal stratigraphical contact between the two lowest groups of the Dalradian succession. This conclusion is supported by observations at the *River Leven* and *Strath Fionan* GCR sites.

The rocks at this site are folded over into a large downward-closing F2 fold, the Beinn Udlaidh Syncline, which lies on its side and has been deeply incised by the River Orchy, to reveal its internal geometry. The gorges and rocky bed of the river expose a superlative section which is invaluable as a natural laboratory in which to study the intricate three-dimensional shape of this fold and its associated minor structures, and to enable its mode of development and complex history to be further unravelled. One aspect of the work of special interest, is that it is the first locality in the western Grampian Highlands where it can be demonstrated that the so-called ‘early’ nappe-like folds formed after an even earlier major deformational and metamorphic event.

References



(Figure 3.29) Map of the closure of the F2 Beinn Udlaidh Syncline in Glen Orchy. The curved axial trace of this fold is due to the intersection of the gently dipping axial surface with the irregular topography, and does not reflect the curvilinear hinge as described in the text or later deformation. Equal-area stereographic projections for some of the structural data are shown. Stereoplot (a) shows the poles to the axial planes of minor folds related to the syncline, together with their computed mean orientation as a great circle (solid line). Stereoplot (b) shows the orientations of stretching lineations (solid triangles; N=41) and minor fold hinges (open circles; N=107), related to the major syncline. The solid line represents the computed best-fit plane containing the fold hinges.

(Figure 3.30) Z-shaped vergence shown by main-phase minor folds, which plunge to the south on the upper limb of the F2 Beinn Udlaidh Syncline in the River Orchy. The structures are seen looking due south from the dam at locality 1, (Figure 3.29), during low-water conditions. The hammer shaft is 78 cm long. (Photo: P.W.G. Tanner.)

(Figure 3.31) Stacked fold hinges of minor folds ('fold mullions') with neutral vergence in the hinge-zone of the F2 Beinn Udlaidh Syncline in the River Orchy at locality 2, (Figure 3.29). The structures are viewed from the south-east, and the hammer shaft is 78 cm long. (Photo: P.W.G. Tanner.)